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RESEARCH MEMORANDUM

TEMPERATURE SURVEY OF THE WAKE OF TWO CLOSELY LOCATED PARALLEL JETS

By John L. Sloop and Gerald Morrell

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

February 6, 1950

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

TEMPERATURE SURVEY OF THE WAKE OF TWO CLOSELY LOCATED PARALLEL JETS

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SUMMARY

A temperature survey was made of the wake of two closely located parallel jets emerging into the atmosphere from two types of twin convergent nozzle: (1) 1-inch-diameter throats with centers 1.42 inches apart, and (2) 0.863-inch-diameter throats with centers 1.5 inches apart followed by simulated 1-inch-diameter shrouds 0.466 inch long. The shrouds simulated only the geometry of a cooling-air shroud and no attempt was made to simulate the flow of cooling air through the shroud. The expansion ratio was 9.7; average jet total temperature, 1334° F; and ratio of specific heats, about 1.27.

The results indicated that for the twin unshrouded nozzles a "piling-up" of hot gas occurred in the region between the two jets. For the twin shrouded nozzles, the results showed much less "piling-up" in the region between the two jets and less interaction of the two jets on each other than for the unshrouded nozzles.

INTRODUCTION

The use of jet-propulsion power plants in aircraft has, in some applications, introduced problems of overheating of aircraft surfaces by the exhaust jets. In applications involving the use of two closely located jet power plants, the aircraft-surface temperature may be greatly increased by the combined effect of the two exhaust jets.

An investigation was conducted at the NACA Lewis laboratory during February to April 1949 to determine the spatial distribution of temperature in the wake of two closely located jets as a guide for establishing the clearance necessary between the aircraft structure and the jets to avoid damage to the airplane. The experiments were conducted at an expansion ratio of 9.7; the average jet total temperature was 1334° F. Temperature surveys

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at positions ranging from 1.0 to 5.5 inches downstream of the nozzle exits were made of the wake of jets from two types of twin nozzle. The first type consisted of two parallel convergent nozzles with each throat 1 inch in diameter and centers 1.42 inches apart. The second type consisted of two parallel convergent nozzles with each throat 0.863 inch in diameter, centers 1.50 inches apart, and each throat followed by a 1-inch-diameter geometry-simulated shroud or extension hood 0.466 inch long. These dimensions were chosen for the experiments to furnish information for a particular application but the results should be of general interest.

APPARATUS

The apparatus consisted of a source of hot gases obtained by decomposing hydrogen peroxide, two types of twin convergent nozzle, a 9-thermocouple rake, and an 11-thermocouple rake. The assembly is shown in figure 1.

The source of hot gases consisted of an experimental rocket apparatus modified to use concentrated hydrogen peroxide (90 percent) and a catalyst (sodium permanganate solution) to decompose the peroxide. Helium was used to force the peroxide and the catalyst through spray nozzles into a decomposition chamber. The flow, and hence chamber pressure, was controlled by regulation of the helium pressure. The decomposition chamber was a flanged, insulated, 4-inch-inside-diameter Inconel tube, 20 inches long, and was provided with pressure and temperature taps.

A sketch of the plate containing the twin unshrouded nozzles is shown in figure 2(a). The two convergent nozzles had 1.00-inch-diameter throats spaced 1.42 inches or diameters apart, center to center. A sketch of the plate containing twin shrouded nozzles is shown in figure 2(b). The two convergent nozzles had 0.863-inch-diameter throats with centers 1.50 inches apart (1.74 diam) and, in addition, each nozzle had a 1-inch-diameter geometry-simulated shroud or extension hood 0.466 inch long. No attempt was made to simulate the flow of cooling air through the shroud.

The pressure in the decomposition chamber was measured by a continuous-recording Bourdon-type instrument. The temperature of the gases in the decomposition chamber was measured with an unshielded chromel-alumel thermocouple located near the exit of the decomposition chamber.

Thermocouple rake I used to obtain the temperature distribution in the wake of both types of twin nozzle is shown in figure 3(a). Rake II, used with the twin shrouded nozzles only, is shown in figure 3(b). Both rakes consisted of unshielded chromel-alumel thermocouples in probes 2 inches long reinforced by 1/8-inch-diameter steel tubes. The leads were grouped in a flat streamlined body approximately 1/4 inch thick. The probes were mounted parallel to the direction of flow of the jets to obtain a high recovery factor. The rakes were mounted on 1/2-inch threaded rods, which permitted adjustment of the rakes in a direction perpendicular to the jet-flow direction. The plate holding the rod was so mounted as to permit adjustment of the rakes in a direction parallel to the jet-flow direction (fig. 1(b)). Each thermocouple was connected to a separate continuous-recording self-balancing potentiometer.

PROCEDURE

For each run the thermocouple rake was first manually positioned and then the catalyst (hydrogen peroxide) system was operated until the recorded temperatures reached steady values. (Usually an operating period of 8 to 10 sec was required.) The rakes were mounted to survey one quadrant of the twin-jet wake at distances ranging from about 1.0 to 5.5 inches downstream of the nozzle-throat exits. Rake positions for the temperature measurements are shown in tables I to III. Positions in the jet wake are measured with respect to an X, Y, Z rectangular-coordinate system with origin at the center point between the nozzles at the throat exits. The Z-axis is in the downstream direction, the Y-axis is the center line between the nozzles, and the X-axis passes through the center of each nozzle. These coordinates are indicated in tables I to III and in each of the figures.

The operating conditions for the runs were:

Decomposition-chamber pressure, lb/sq in. absolute	143 ±4
Expansion ratio	9.7
Theoretical decomposition temperature, °F	1364
Average measured decomposition temperature, °F	1334
Theoretical jet-throat velocity, ft/sec	2255
Decomposition products (of 90-percent hydrogen peroxide):	
Water, percent by weight	58
Oxygen, percent by weight	42
Theoretical ratio of specific heats	1.27
Mean molecular weight of products	22.11
Operating time per run, sec	8 - 10
Hydrogen peroxide flow rate, lb/sec	approx. 3
Sodium permanganate flow rate, lb/sec	approx. 0.09 - 0.15

For convenience in analysis, the temperatures were converted to the dimensionless ratio 1195

$$\frac{T - T_0}{T_j - T_0}$$

where

T measured temperature at any position, °R

T_0 ambient or free-stream temperature, °R

T_j jet total temperature at nozzle exit, °R

The measured decomposition-chamber temperature was used as the jet total temperature; the ambient temperature was considered as the average of the thermocouple readings before a series of consecutive runs. Any rake temperatures higher than the recorded decomposition-chamber temperature were assumed equal to the recorded chamber temperature and any rake temperatures lower than the ambient temperature were considered as equal to the ambient temperature.

The chamber temperature varied from 1210° to 1433° F with an average for all the runs of 1334° F. The errors in the measurement of temperature, although not accurately known, were sufficiently small for the purposes of the experiments. In the low-temperature, low-velocity regions where heat losses and velocity effects are small, the accuracy of temperature measurement was about 10° F in most cases. In the high-temperature, high-velocity regions, a comparison of the measured decomposition-chamber temperature (where heat losses and velocity effects were at a minimum) with the wake temperatures obtained indicated agreement to within 2 percent in all of the cases but three. These results indicated a high recovery factor for the thermocouples. Sufficient data were obtained to indicate definite trends and to balance the few individual discrepancies.

Several runs were made to determine if insulation of the nozzle plate on the downstream side would appreciably alter the measured temperatures. For these runs, the nozzle plate was insulated with alternate layers of asbestos (three layers) and aluminum foil (two layers) having a total thickness of 1/4 inch.

RESULTS AND DISCUSSION

Twin Unshrouded Nozzles

The data obtained from the experiments with the twin unshrouded nozzles are shown in table IV; table V shows the data in dimensionless form. A typical plot of the data from table V is shown in figure 4 where temperature ratio is plotted against Y for the position 1 diameter downstream of the nozzle-throat exits.

Contours of constant temperature ratio around the jets in the X, Y plane at three downstream positions obtained from the curves of figure 4 and similar curves for the various downstream positions are presented in figure 5. The contours show a "piling-up" of hot gas in the region between the jets. The contours also indicate a definite influence of the jets on each other that extend at least as far as the Y, Z planes through the centers of the jets. This interaction effect is evident from a comparison of the shapes of the contours on the inner and outer sides of the jet.

Contours of constant temperature ratio along the plane through the center line between the jets (Y,Z plane; $X,0$) are shown in figure 6. The contours for temperature ratios greater than 0.4 pass through a maximum value of Y in the region from 2 to 3 diameters downstream of the exits, and for the curves for temperature ratios less than 0.4, the value of Y continuously increases in the downstream direction. Figure 6 shows that the region having a temperature ratio of 0.1 is 1.35 diameters above the X,Z plane (through $Y = 0$) at 1 diameter downstream from the nozzle-throat exits and continuously increases to approximately 2.1 diameters above the X, Z plane at 3.5 diameters downstream. The region having a temperature ratio of 0.6 is 0.7 diameter above the X, Z plane at 1 diameter downstream from the nozzle-throat exits, reaches a maximum distance of 1.2 diameters above the X, Z plane at 2.5 diameters downstream, and decreases to 1.1 diameters above the X, Z plane at 3.5 diameters downstream.

Twin Nozzles with Twin Geometry-Simulated Shrouds

The results for the experiments with the twin shrouded nozzles are presented in a manner similar to those for the twin unshrouded nozzles. The data are shown by tables VI and VII and a typical plot of the data from table VII (for the downstream position 4 diam from the nozzle-throat exits) is shown in figure 7. In general, the data for the twin shrouded nozzles were more scattered than the data obtained for the twin unshrouded nozzles; the scatter was greatest for positions near the jet exits.

Contours of constant temperature ratio around the jets at several downstream positions (X, Y planes), which were obtained from the curves of figure 7 and similar curves for other downstream positions, are presented in figure 8. The contours for the twin shrouded nozzles show much less piling-up of hot gas in the region between the two jets than was found for the unshrouded nozzles (fig. 5); this difference is greater than would be anticipated by the small change in spacing of the two types of nozzle. The effect of the shrouds has been to decrease greatly the spreading out of the jets after emergence from the shrouds and this decrease considerably lessened the mutual effect of the two jets on each other in the atmosphere. Because there was no cooling air flow, the shrouds were, in effect, extensions of nozzles. The gas expands to a lower pressure in the shrouds than at the throats; in addition, the sudden expansion in the shrouds produces energy losses. These effects decrease the amount of free expansion in the atmosphere and therefore the mutual interference between the two jets. 1195

Contours of constant temperature ratio in the plane through the center line between the jets (Y, Z plane; X = 0) are shown in figure 9. These data show that the curve having a temperature ratio of 0.1 has a Y value of 0.64 diameter at 1.2 diameters downstream of the nozzle-throat exits, increases to a value of 1.1 diameters at 3.5 diameters downstream, and continues to increase to a value of 1.8 diameters at 6 diameters downstream. The curve for a temperature ratio of 0.6 remains less than the nozzle-throat radius for a distance of about 6 diameters downstream of the nozzle throat. Although the curves of figure 9 for the twin shrouded nozzles show considerably less spreading than those for the twin unshrouded nozzles (fig. 6), the general trend of the curves for the two types of nozzle is similar. As was observed for the twin unshrouded nozzles, the plots for the twin shrouded nozzles show that the curves for temperature ratios larger than 0.4 pass through a maximum value of Y in the region between 2 and 4 diameters from the nozzle throat and for the curves for temperature ratios less than 0.4 the value of Y continuously increases in the downstream direction.

The data for the runs with the nozzle plate insulated are shown in tables VIII and IX. These data were plotted in the same manner as the data for the uninsulated nozzle plates and the results are indicated by the tailed data points in figure 9. The results of the runs with insulated nozzle plates show that in all cases but one the maximum deviations are of the order of

0.1 diameter and therefore are not large enough to affect the trends and the comparisons obtained with uninsulated nozzle plates.

A comparison of the curves for a temperature ratio of 0.1 for the twin unshrouded and twin shrouded nozzles is shown in figure 10. Although a strict comparison of the results from the two types of twin nozzle used is impossible because of the difference in the ratio of the distance between nozzle axes to the diameter of the nozzle proper (1.42 diam for the unshrouded nozzles, 1.74 diam for the shrouded nozzles), the large difference in the results obtained for the two types of nozzle indicates clearly, for distances up to 3.5 diameters downstream, the effective role of shrouds in reducing interference between two expanding jets in close proximity.

In the application of the results obtained to other physical situations, consideration should be given to scale effects and Reynolds number effects. No attempt was made in these determinations to simulate the cooling-air flow through the shroud, which would be expected to alter the temperature distribution in the jets to some extent.

SUMMARY OF RESULTS

A temperature survey was made of the wake of two jets emerging into the atmosphere from two types of twin, parallel, convergent nozzle: (1) 1-inch-diameter throats with centers 1.42 inches apart, and (2) 0.863-inch-diameter throats with centers 1.5 inches apart (1.74 diam) followed by a geometry-simulated shroud 1 inch in diameter and 0.466 inch long. No attempt was made to simulate the flow of cooling air through the shroud. The expansion ratio was 9.7; the average jet total temperature was 1334° F; and the ratio of specific heats, about 1.27. The temperature measurements are presented in the dimensionless ratio of measured-temperature difference from ambient to jet-total-temperature difference from ambient. Spatial positions are presented in terms of nozzle-throat diameter. Temperature measurements made in the wake from the two types of twin nozzle used gave the following results:

1. For the twin unshrouded nozzles, a piling-up of hot gas occurred in the region between the two jets and the interaction effect of the jets on each other was evident as far as the region above the centers of the jets.

2. Although the results using the two types of nozzle are not strictly comparable because of the difference in the nozzle spacings, for the twin shrouded nozzles the piling-up of hot gas in the region between the jets and the interaction effect of the two jets on each other were much less than for the unshrouded nozzle.

3. For the twin unshrouded nozzles and midway between the nozzles, the region where the temperature ratio was 0.1 was 1.35 diameters above the plane through the axes of the two nozzles at 1 diameter downstream of the nozzle-throat exits and continuously increased to approximately 2.1 diameters above this plane at 3.5 diameters downstream. The region having a temperature ratio of 0.6 was 0.7 diameter above the plane through the nozzle axes at 1 diameter downstream of the nozzle-throat exits, reached a maximum distance of 1.2 diameters above this plane at 2.5 diameters downstream, and decreased to 1.1 diameters above this plane at 3.5 diameters downstream.

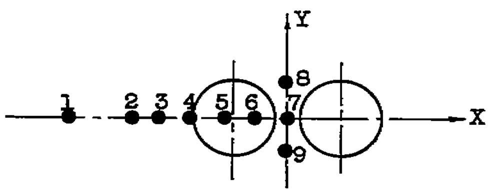
4. For the twin shrouded nozzles and midway between the nozzles, the region having a temperature ratio of 0.1 was 0.64 diameter above the plane through the nozzle axes at 1.2 diameters downstream of the nozzle-throat exits, increased to a distance of 1.1 diameters above the plane through the jet centers at 3.5 diameters downstream, and continued to increase to a distance of 1.8 diameters above the plane through the jet centers at 6 diameters downstream.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

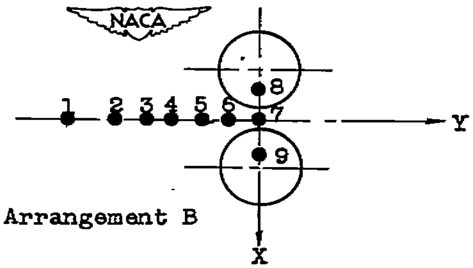
TABLE I - RAKE POSITIONS WITH RESPECT TO TWIN UNSHROUDED NOZZLES

[Z, distance downstream from nozzle-throat exits; 1 diameter = 1 in.]

Run	Arrange-ment	Key thermo-couple	Positions of key thermocouple (diameter)		
			X	Y	Z
8	A	7	0	1.5	2
9	A	7	0	1.25	2
10	A	7	0	1.0	2
11	A	7	0	.75	2
12	A	7	0	0	2
13	A	7	0	2.5	3.5
14	A	7	0	2.0	3.5
15	A	7	0	1.5	3.5
16	A	7	0	.75	3.5
17	A	7	0	0	3.5
18	A	7	0	1.0	1
19	A	7	0	.75	1
20	A	7	0	.5	1
21	A	7	0	0	1
22	B	7	0	0	1
23	B	7	0	0	2
24	B	7	0	0	3.5
25	B	7	.25	0	3.5
26	B	7	.25	0	2
27	B	7	.25	0	1



Arrangement A

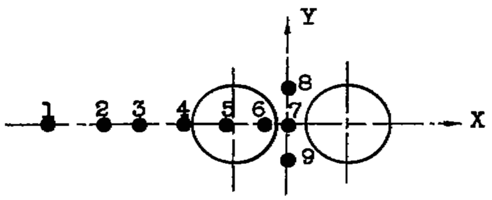


Arrangement B

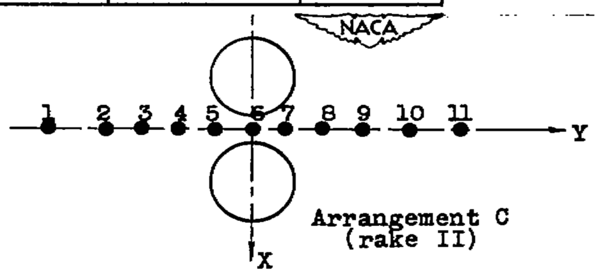
TABLE II - RAKE POSITIONS WITH RESPECT TO TWIN SHROUDED NOZZLES

[Z, distance downstream from nozzle-throat exits; 1 diameter = 0.863 in.]

Run	Arrangement	Key thermocouple	Positions of key thermocouple (diameter)		
			X	Y	Z
28	A	7	0	0	1.41
29	A	7	0	.58	1.41
30	A	7	0	.87	1.41
31	A	7	0	1.16	1.41
32	A	7	0	1.45	1.41
33	A	7	0	0	2.28
34	A	7	0	1.16	2.28
35	A	7	0	.87	2.28
36	A	7	0	.87	4.02
37	A	7	0	1.45	4.02
38	A	7	0	1.74	4.02
39	A	7	0	0	4.02
40	A	7	0	1.16	4.02
41	C	6	0	0	4.02
42	C	6	0	0	2.28
43	C	6	0	0	1.41
44	C	6	0	0	1.12
45	C	6	0	0	5.17
46	C	6	0	0	6.33
47	C	6	0	0	1.12
48	C	6	0	0	1.41
49	C	6	0	0	2.86
50	A	7	0	.29	2.28
51	A	7	0	.58	2.28
52	A	7	0	.87	2.28



Arrangement A (rake I)



Arrangement C (rake II)

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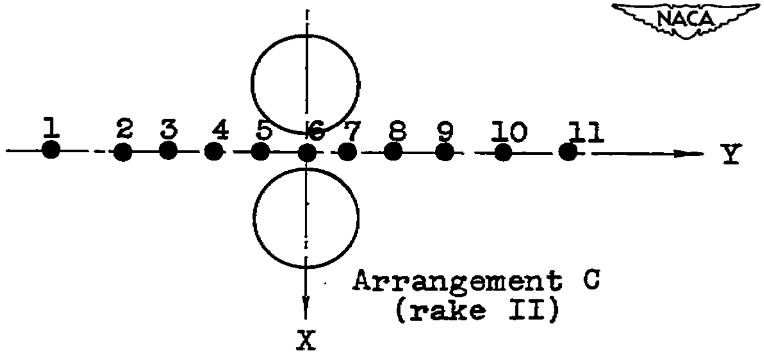
TABLE III - RAKE POSITIONS WITH RESPECT TO TWIN SHROUDED NOZZLES; NOZZLE PLATE INSULATED

Run	Arrangement	Key thermocouple	Positions of key thermocouple (diameter)		
			X	Y	Z
53	C	6	0	0	1.41
54	C	6	0	0	2.28
55	C	6	0	0	4.02
56	C	6	0	0	2.28
57	C	6	0	0	1.12



Arrangement C
(rake II)

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TABLE IV - TEMPERATURES OBTAINED IN WAKE FROM TWIN UNSHROUDED NOZZLES

Run	Ambient temperature (°F)	Chamber temperature (°F)	Chamber pressure (lb/sq in abs.)	Thermocouple Temperature (°F)								
				1	2	3	4	5	6	7	8	9
8	32	1265	143	30	24	40	24	80	240	295	1040	40
9		1250	143	32	24	48	80	160	320	480	1168	112
10		1250	140	32	24	64	352	736	720	917	1200	316
11		1232	143	40	48	104	655	1160	1190	1150	1232	576
12		1232	143	32	32	480	1225	1328	1328	1250	1170	1103
13	37	1313	145	32	24	45	32	64	80	80	208	20
14		1328	144	32	24	48	40	112	184	209	408	56
15		1313	146	80	96	120	144	208	287	408	752	168
16		1296	143	32	32	184	552	993	960	1096	1296	544
17	42	1320	143	40	80	400	993	1328	1328	1296	1274	1137
18		1313	144	32	48	96	128	176	160	360	1218	72
19		1320	145	48	48	96	720	1280	1200	865	1310	216
20		1350	144	32	22	80	928	1296	1263	993	1325	320
21		1343	143	48	64	168	1248	1369	1360	1247	1255	1178
22	32	1345	143	28	24	88	184	656	1328	1295	1320	1287
23		1330	141	32	32	160	616	1280	1310	1310	1320	1295
24		1338	141	32	64	240	504	1040	1303	1328	1280	1270
25		1328	144	40	192	480	960	1287	1320	1328	1295	1280
26		1310	143	80	80	472	975	1263	1335	1262	1255	1200
27		1310	143	48	40	136	768	1263	1232	1295	1310	1190

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TABLE V - TEMPERATURE RATIO FOR WAKE FROM
TWIN UNSHROUDED NOZZLES

Run	Thermocouple								
	1	2	3	4	5	6	7	8	9
	Temperature ratio								
8	0	0	0.01	0	0.04	0.17	0.21	0.82	0.01
9	0	0	.01	.04	.11	.24	.37	.93	.07
10	0	0	.03	.26	.58	.56	.73	.96	.23
11	.01	.01	.06	.52	.94	.96	.93	1.00	.45
12	0	0	.37	.99	1.00	1.00	1.00	.95	.89
13	0	0	.01	0	.02	.03	.03	.13	0
14	0	0	.01	0	.06	.11	.13	.29	.01
15	.03	.05	.07	.08	.13	.20	.29	.56	.10
16	0	0	.12	.41	.76	.73	.84	1.00	.40
17	0	.03	.28	.74	1.00	1.00	.98	.96	.86
18	0	0	.04	.07	.11	.09	.25	.93	.02
19	0	0	.04	.53	.97	.91	.64	.99	.14
20	0	0	.03	.68	.96	.93	.73	.98	.21
21	0	.02	.10	.93	1.00	1.00	.93	.93	.87
22	0	0	.04	.12	.48	.99	.96	.99	.96
23	0	0	.10	.45	.96	.98	.98	.99	.97
24	0	.02	.16	.36	.77	.97	.99	.96	.95
25	.01	.12	.35	.72	.97	.99	1.00	.97	.96
26	.04	.04	.34	.74	.96	1.00	.96	.96	.91
27	.01	.01	.08	.58	.96	.94	.99	1.00	.91

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TABLE VI - TEMPERATURES OBTAINED IN WAKE FROM TWIN SHROUDED NOZZLES

Run	Ambient temperature (°F)	Chamber temperature (°F)	Chamber pressure (lb/sq in. abs.)	Thermocouple 1	2	3	4	5	6	7	8	9	10	11
				Temperature (°F)										
28	48	1433	144	48	47	80	1185	1383	1343	1295	352	832		
29		1433	143	56	48	100	1240	1365	1330	1040	1375	80		
30		1400	142	49	48	48	432	928	312	96	1287	64		
31		1415	141	48	44	35	40	64	60	64	128	56		
32		1416	141	48	44	48	32	48	72	56	54	50		
33		1330	145	49	48	336	1120	1480	1287	1310	896	880		
34		1312	144	48	44	48	40	56	64	65	320	52		
35	56	1400	144	60	48	54	195	448	376	144	952	56		
36		1390	143	62	48	88	344	480	424	320	911	72		
37		1400	139	60	48	64	44	64	72	88	224	64		
38		1375	145	64	50	60	40	56	64	80	80	64		
39		1325	142	64	54	448	1087	1335	1224	1218	1030	384		
40		1280	140	62	48	72	190	240	216	224	592	72		
41		1360	145	68	56	200	345	867	1218	992	432	216	112	(a)
42		1407	143	72	64	88	248	1120	1330	1102	288	88	92	(a)
43		1415	145	72	62	80	80	496	896	416	104	86	96	(a)
44		1360	144	72	56	64	64	384	736	181	72	72	80	101
45		1383	143	74	112	288	520	1010	1190	880	472	376	272	154
46		1360	144	74	128	280	472	975	1230	856	560	511	456	242
47	47	1340	143	66	48	48	106	352	1135	336	88	64	72	66
48		1375	140	62	56	50	50	336	913	368	72	64	76	66
49		1390	145	64	56	54	256	848	1160	800	176	76	80	75
50		1410	143	62	48	88	1160	1368	1365	1096	945	144		
51		1390	145	64	56	200	1070	1247	832	591	1310	80		
52		1345	145	64	50	96	760	1169	751	384	1208	72		

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[a]Recorder not functioning properly.

TABLE VII - TEMPERATURE RATIO OBTAINED IN WAKE FROM TWIN SHROUDED NOZZLES

Run	Thermocouple										
	1	2	3	4	5	6	7	8	9	10	11
	Temperature ratio										
28	0	0	0.02	0.82	0.96	0.94	0.90	0.22	0.57		
29	.01	0	.04	.86	.95	.93	.72	.96	.02		
30	0	0	0	.28	.65	.20	.04	.92	.01		
31	0	0	0	0	.01	.01	.01	.06	0		
32	0	0	0	0	0	.02	.01	0	0		
33	0	0	.22	.84	1.00	.97	.98	.66	.65		
34	0	0	0	0	.01	.01	.01	.22	0		
35	0	0	0	.10	.29	.24	.07	.67	0		
36	0	0	.02	.22	.32	.28	.20	.64	.01		
37	0	0	.01	0	.01	.01	.02	.12	.01		
38	.01	0	0	0	0	.01	.02	.02	.01		
39	.01	0	.31	.81	1.00	.92	.92	.77	.26		
40	0	0	.01	.11	.15	.13	.14	.44	.01		
41	.01	0	.11	.22	.62	.89	.72	.29	.12	0.04	
42	.01	.01	.02	.14	.79	.94	.77	.17	.02	.03	
43	.01	0	.02	.02	.32	.62	.26	.04	.02	.03	
44	.01	0	.01	.01	.25	.52	.10	.01	.01	.02	0.03
45	.01	.04	.17	.35	.71	.85	.62	.31	.24	.16	.07
46	.01	.06	.17	.32	.70	.90	.61	.39	.35	.31	.14
47	.01	0	0	.05	.24	.84	.22	.03	.01	.03	.01
48	.01	.01	0	0	.21	.65	.24	.02	.01	.02	.01
49	.01	0	0	.16	.61	.83	.56	.10	.02	.02	.02
50	.01	0	.03	.82	.97	.97	.78	.66	.07		
51	.01	.01	.11	.76	.89	.58	.41	.94	.02		
52	.01	0	.04	.49	.86	.54	.26	.89	.02		

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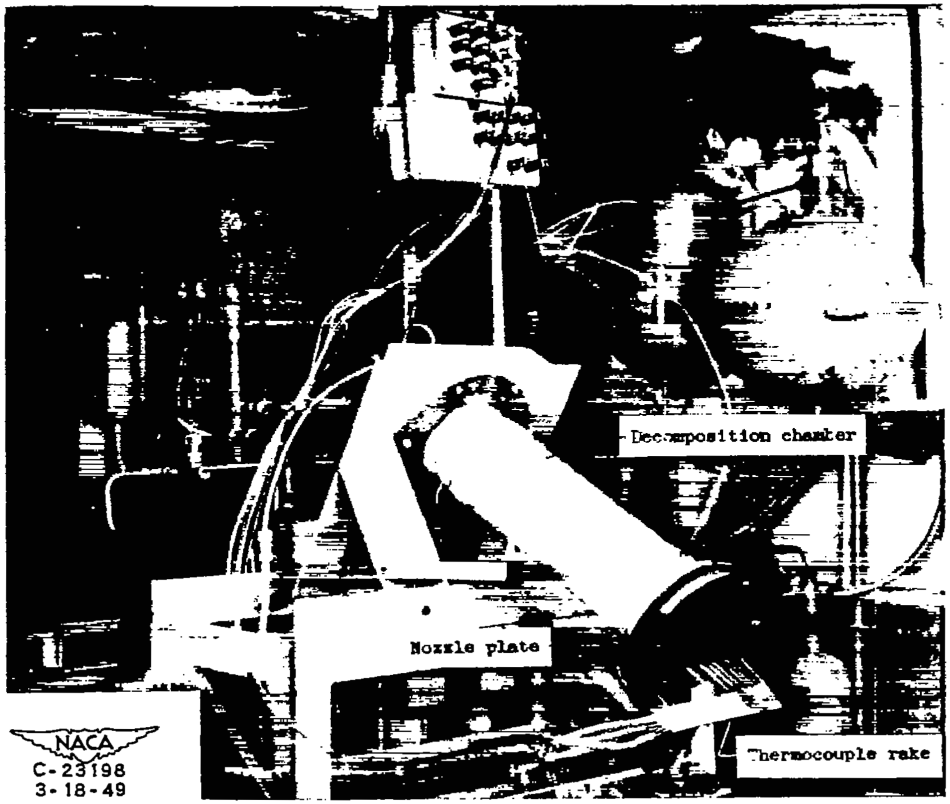
TABLE VIII - TEMPERATURES OBTAINED IN WAKE FROM TWIN SHROUDED NOZZLES; NOZZLE PLATE INSULATED

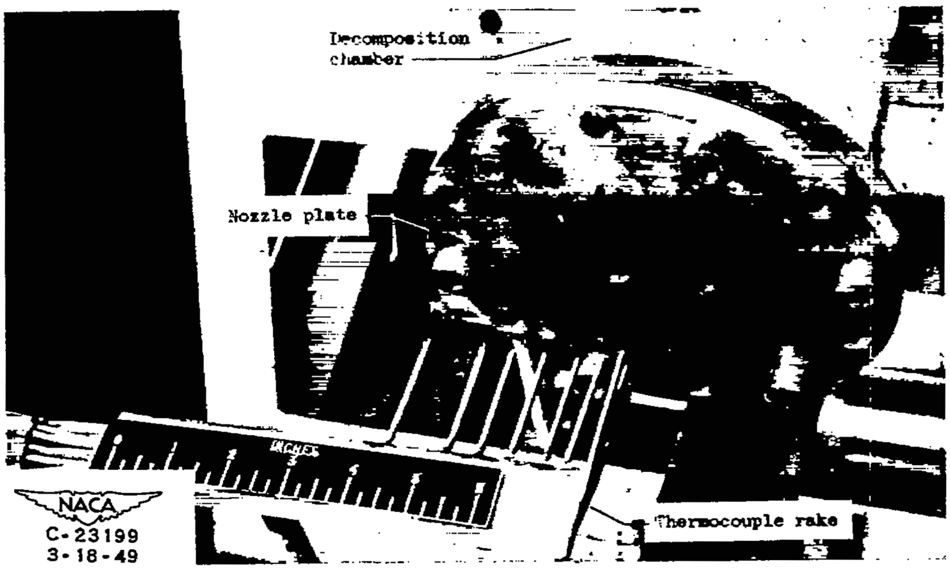
Run	Ambient temperature (°F)	Chamber temperature (°F)	Chamber pressure (lb/sq in. abs.)	Thermocouple										
				1	2	3	4	5	6	7	8	9	10	11
				Temperature (°F)										
53	78	1225	142	70	72	88	88	349	912	672	136	92	80	80
54		1245	140	76	72	94	136	720	1145	928	---	112	104	80
55		1210	141	84	80	176	320	687	1103	928	497	264	152	92
56		1235	142	48	78	96	152	712	1120	975	433	112	104	82
57		1265	141	72	84	92	88	224	704	480	112	88	104	84

TABLE IX - TEMPERATURE RATIO OBTAINED IN WAKE FROM TWIN SHROUDED NOZZLES; NOZZLE PLATE INSULATED

Run	Thermocouple										
	1	2	3	4	5	6	7	8	9	10	11
	Temperature (°F)										
53	0	0	0.01	0.01	0.24	0.73	0.52	0.05	0.01	0	0
54	0	0	.01	.05	.55	.91	.73	----	.03	.02	0
55	.01	0	.09	.21	.54	.91	.75	.37	.16	.07	.01
56	0	0	.02	.06	.55	.90	.78	.31	.03	.02	0
57	0	.01	.01	.01	.12	.53	.34	.03	.01	.02	.01

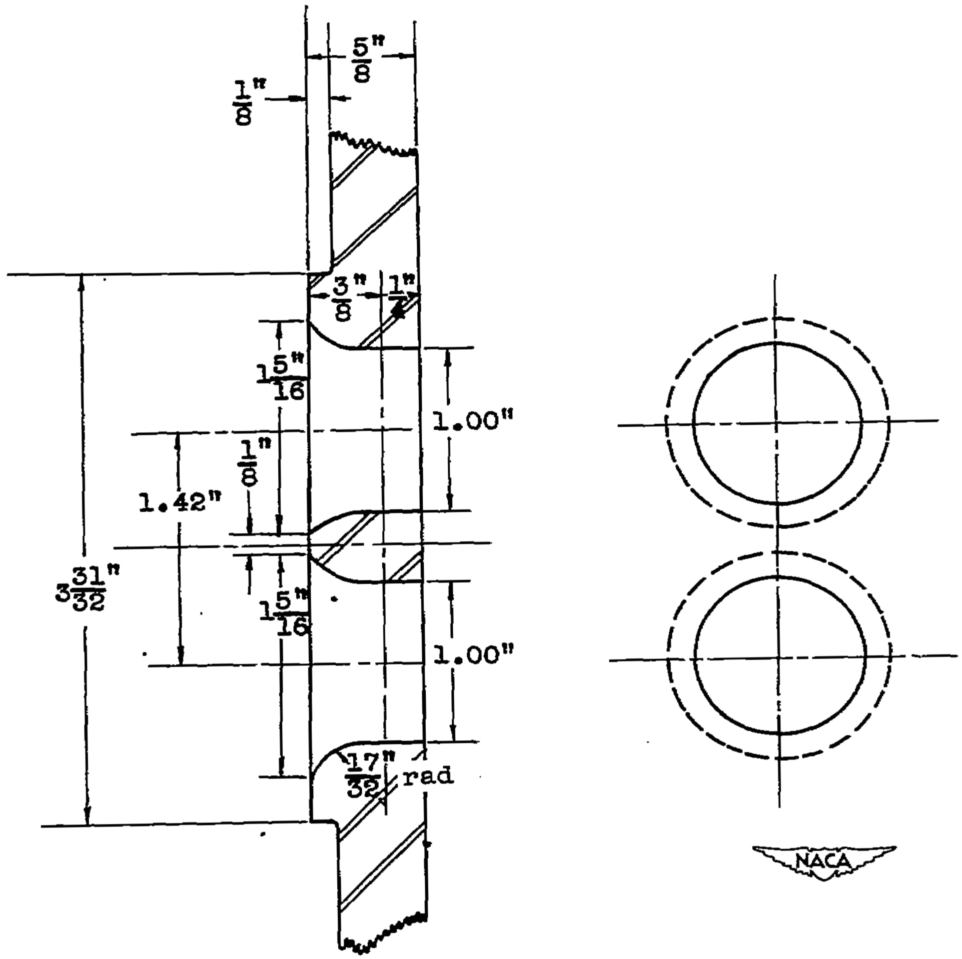


(a) Entire assembly.



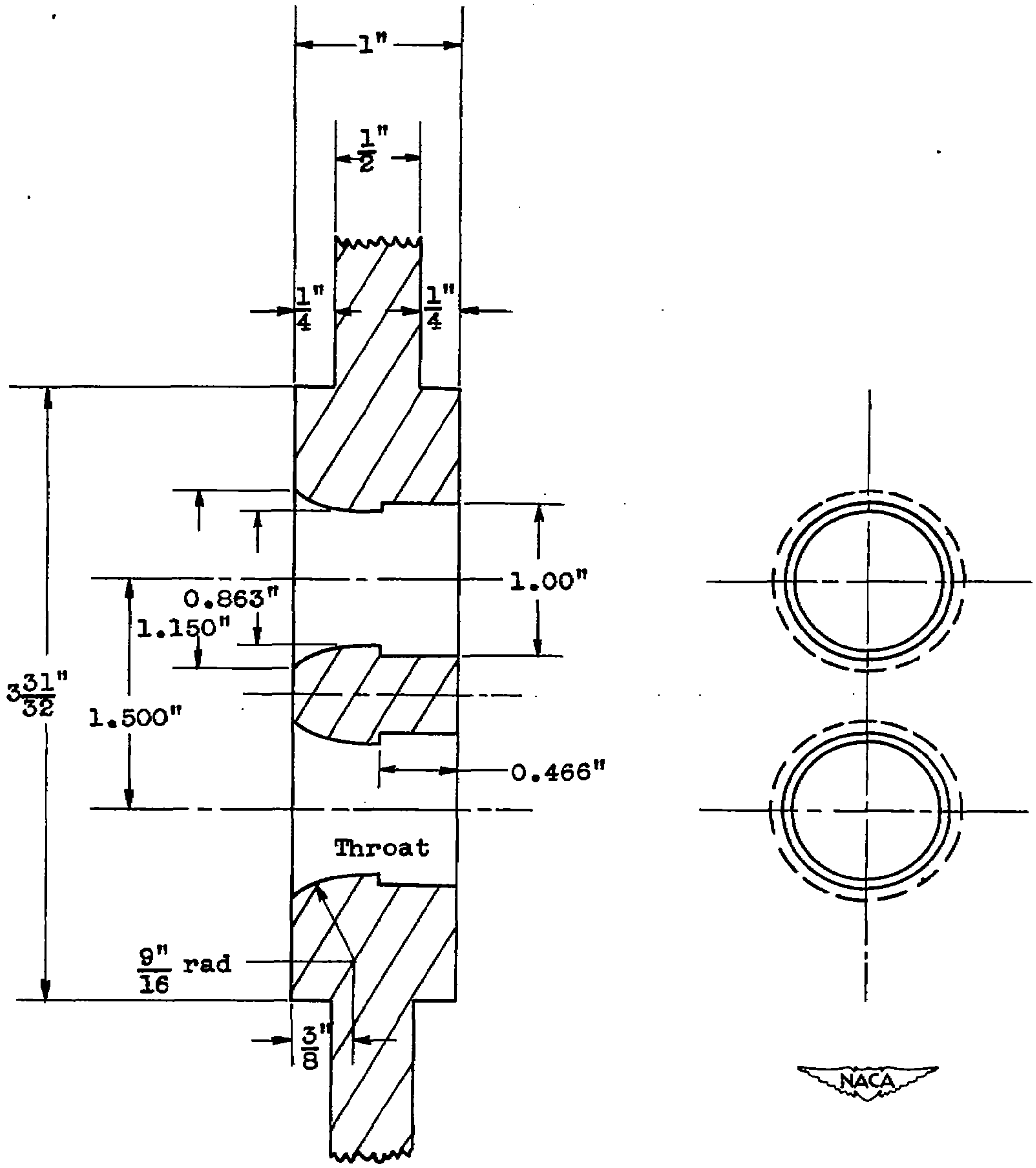
(b) Close-up of nozzle plate and thermocouple rake.

Figure 1. - Experimental assembly showing hydrogen-peroxide decomposition chamber, nozzle plate, thermocouple rake, and auxiliary equipment.



(a) Twin unshrouded nozzles.

Figure 2. - Sketch of plate containing nozzles. Outside diameter of plate, $7\frac{5}{8}$ inches.



(b) Twin shrouded nozzles.

Figure 2. - Concluded. Sketch of plate containing nozzles. Outside diameter of plate, $7\frac{5}{8}$ inches.

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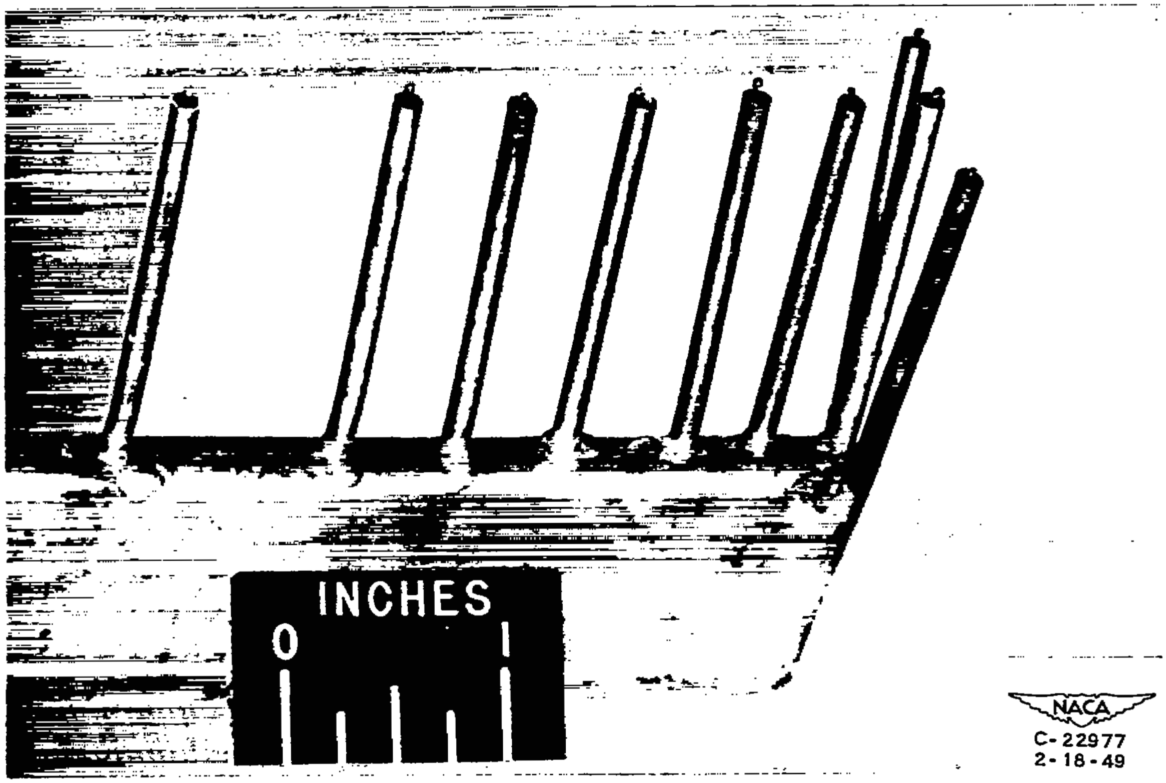
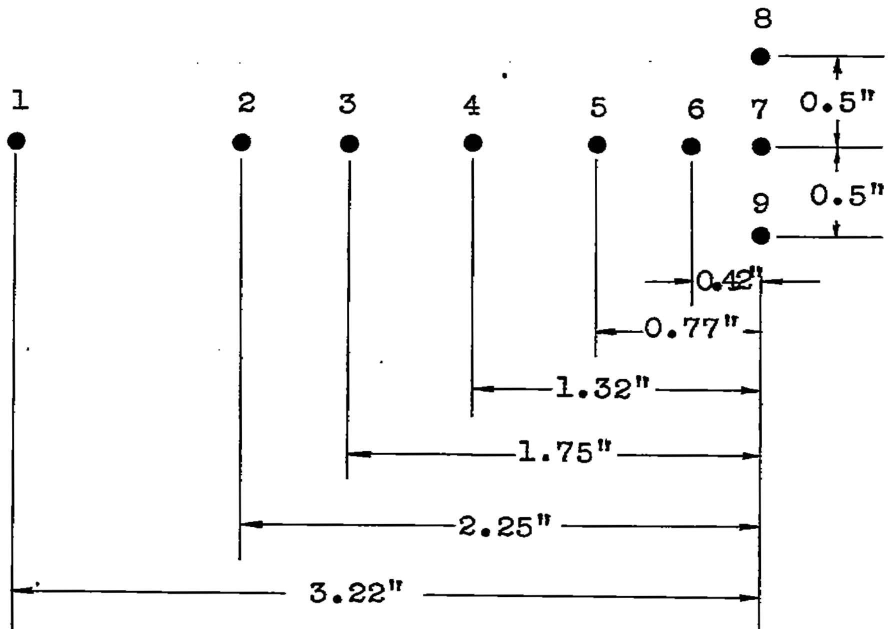
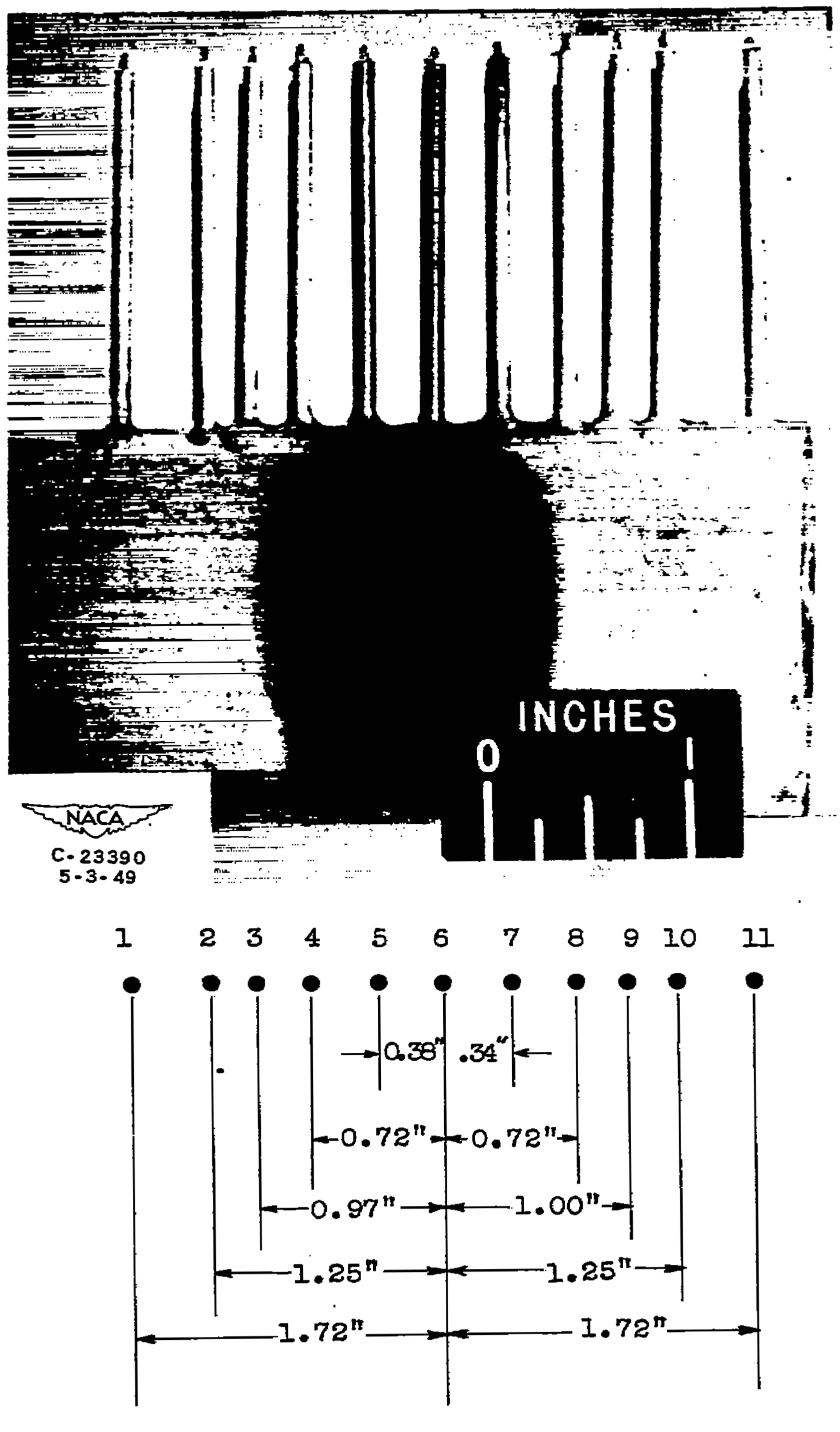




(a) Rake I.

Figure 3. - Thermocouple rakes and spacing.

1195



(b) Rake II.

Figure 3. - Concluded. Thermocouple rakes and spacing.

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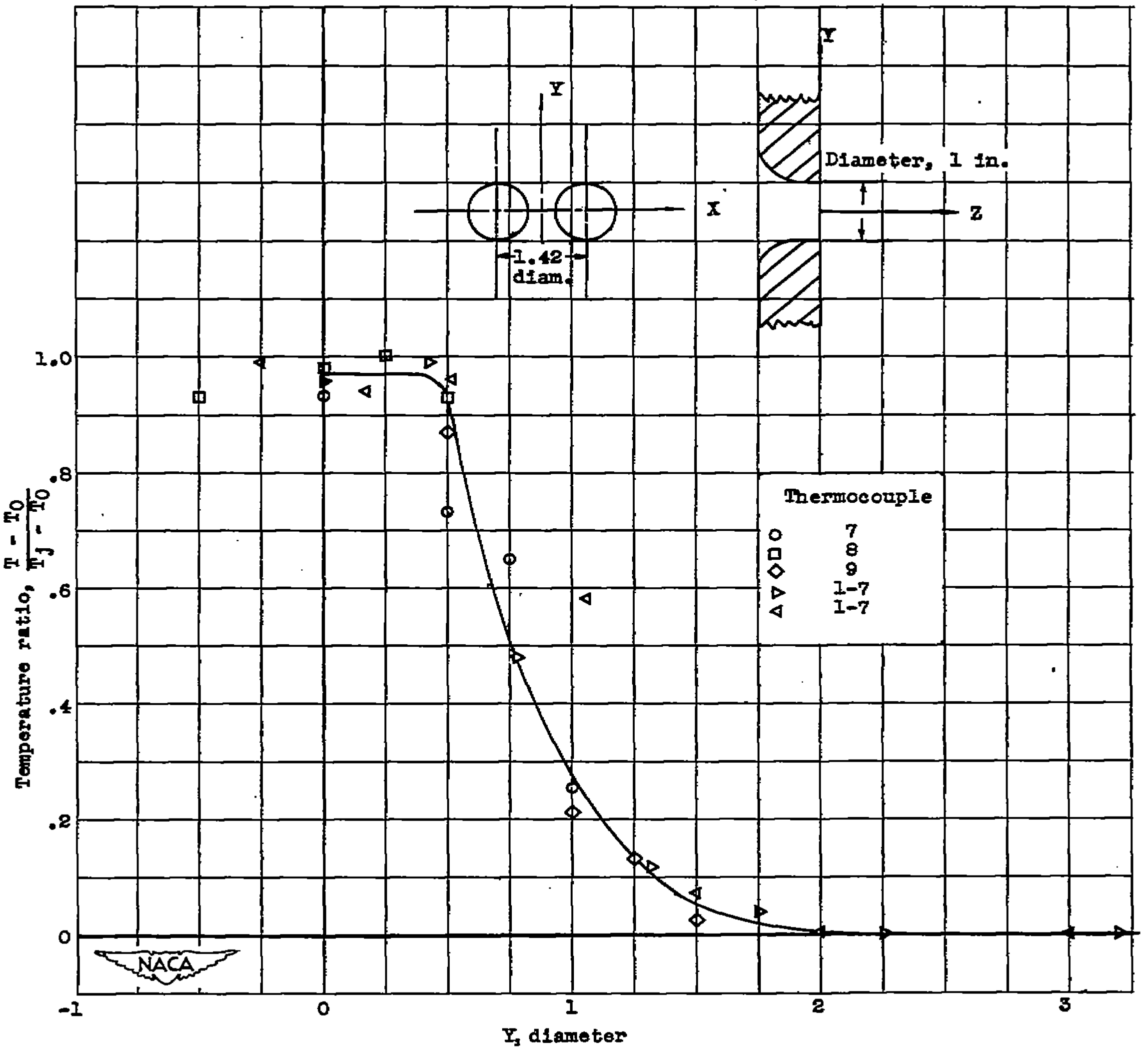
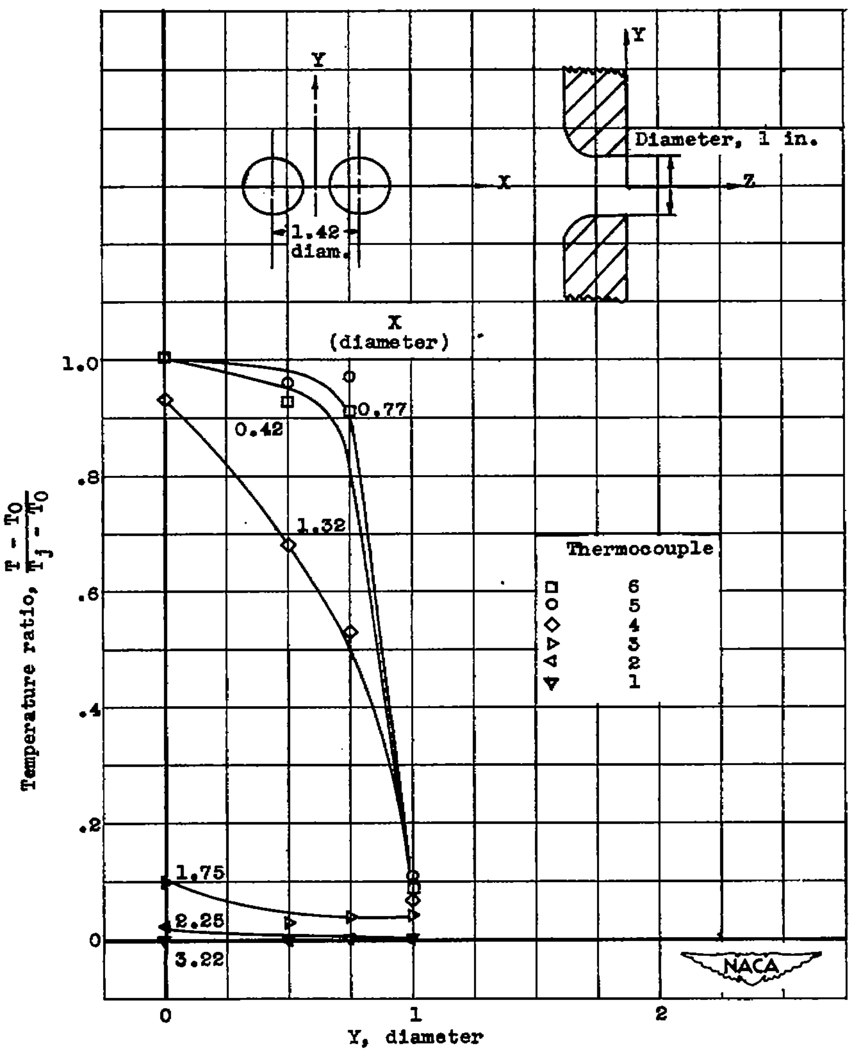
1195



(a) X, 0; Z, 1 diameter.

Figure 4. - Typical plot of data for twin unshrouded nozzles.

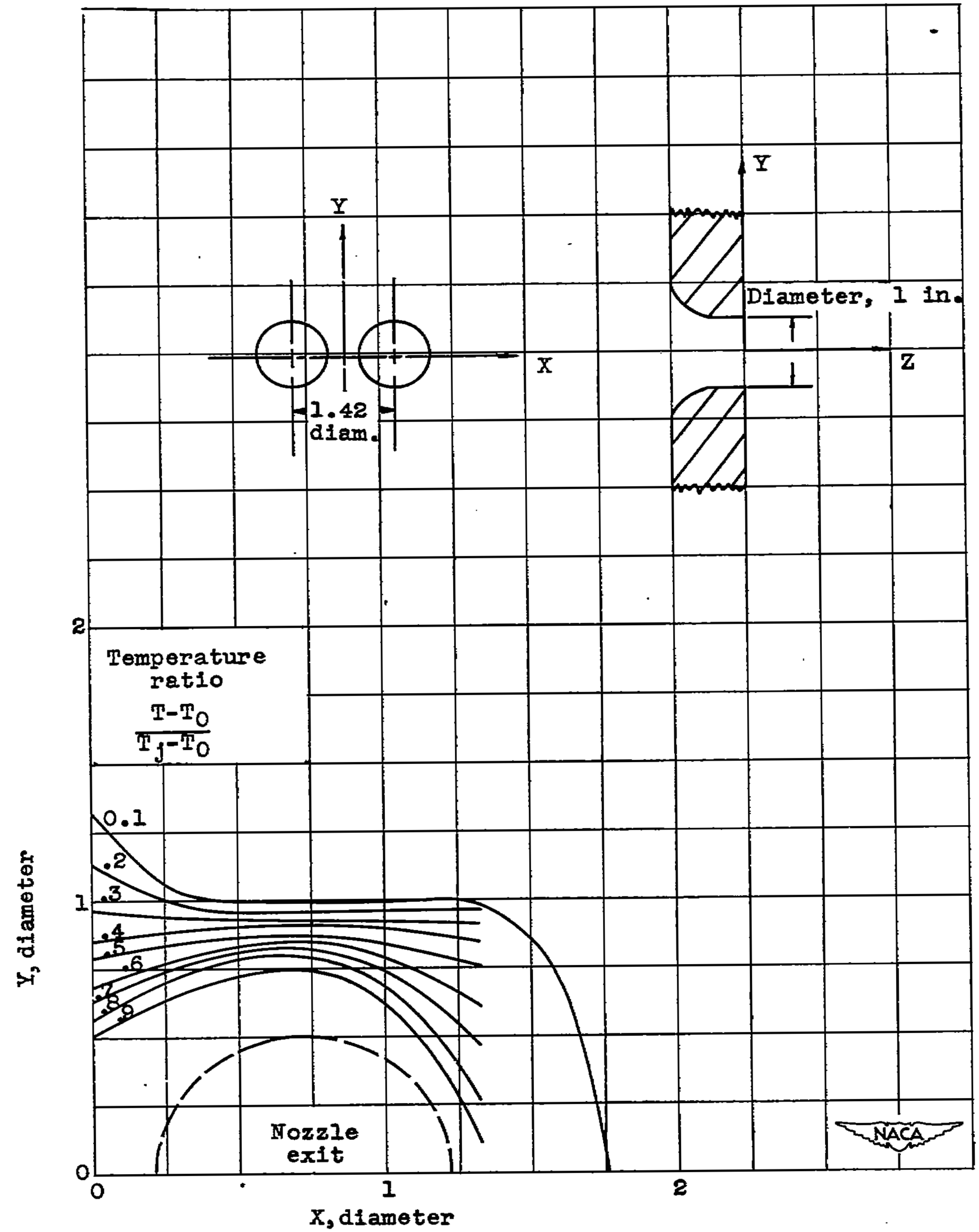
1195



(b) X, variable; Z, 1 diameter.

Figure 4. - Concluded. Typical plot of data for twin unshrouded nozzles.

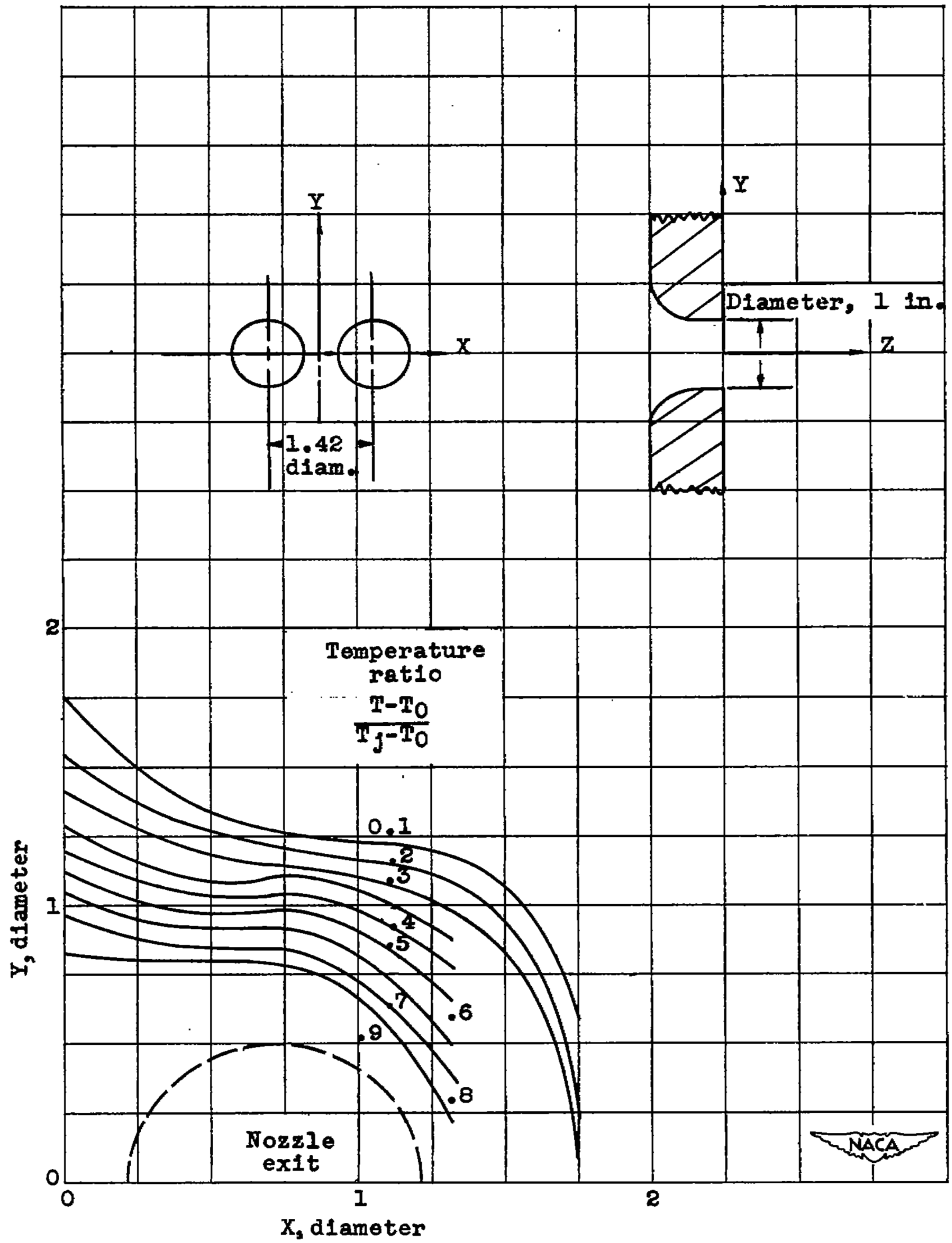
1195



(a) Z, 1 diameter.

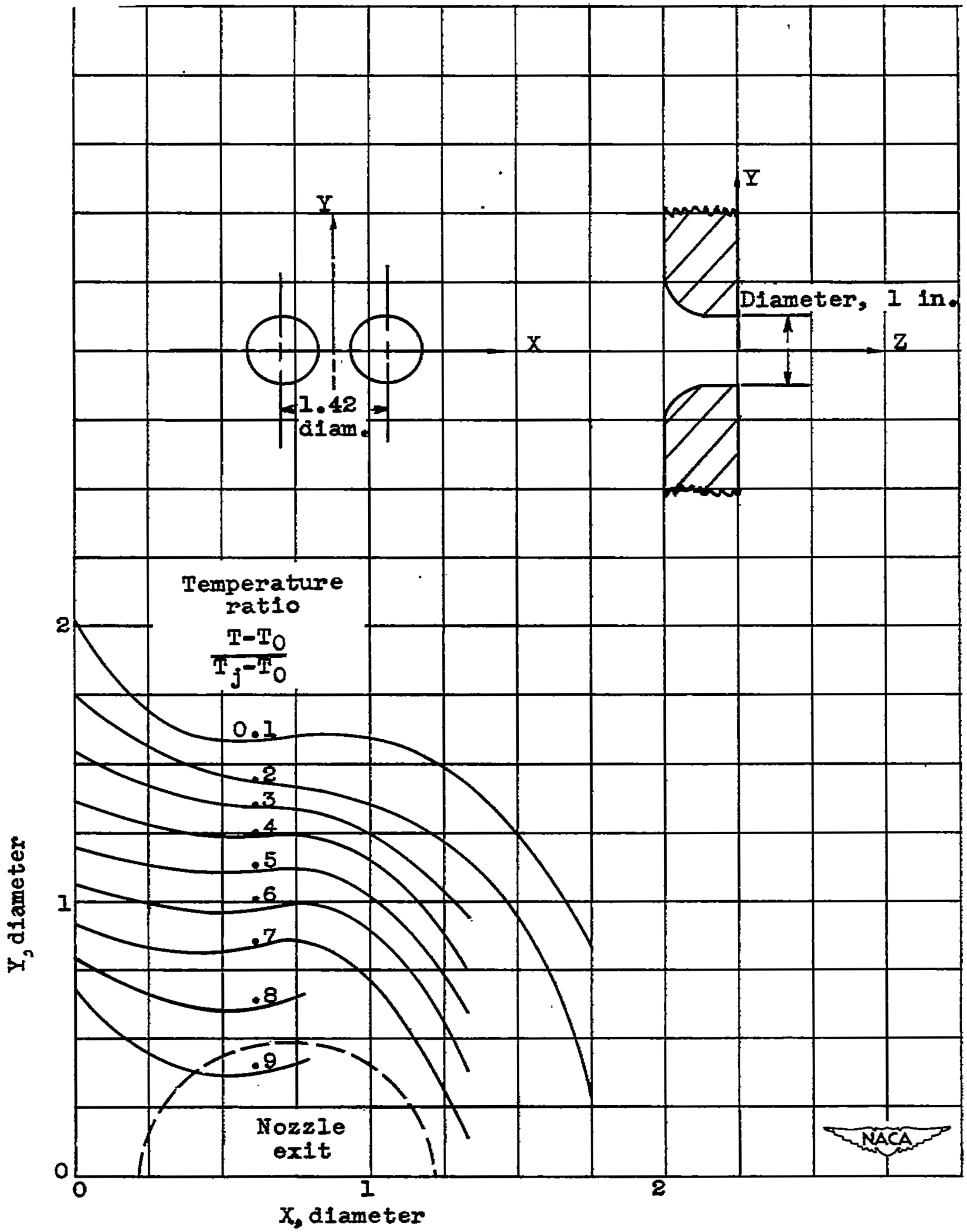
Figure 5. - Temperature-ratio contours of one quadrant of wake from twin unshrouded nozzles.

1195



(b) Z, 2 diameters.

Figure 5. - Continued. Temperature-ratio contours of one quadrant of wake from twin unshrouded nozzles.



(c) Z, 3.5 diameters.

Figure 5. - Concluded. Temperature-ratio contours of one quadrant of wake from twin unshrouded nozzles.

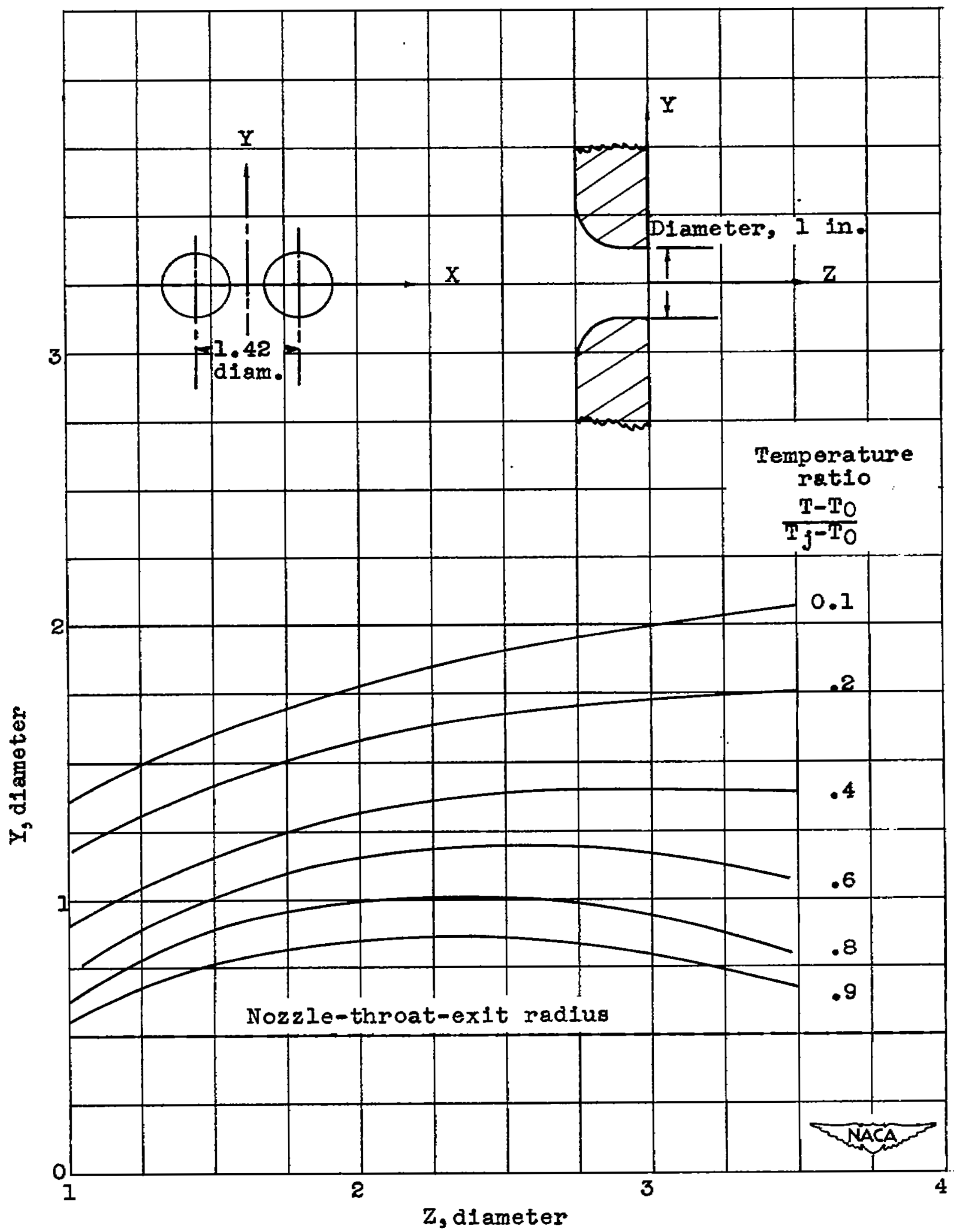
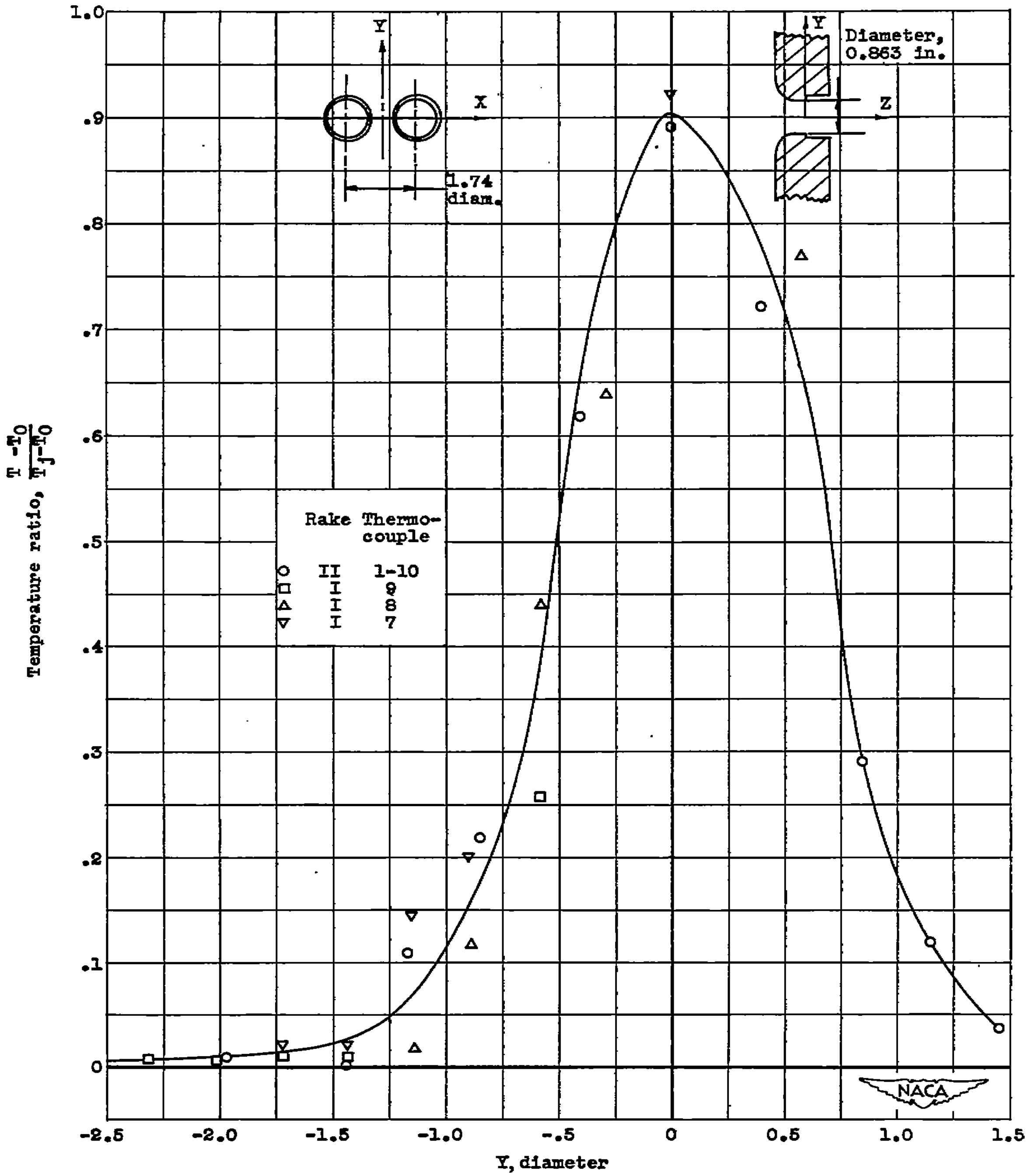


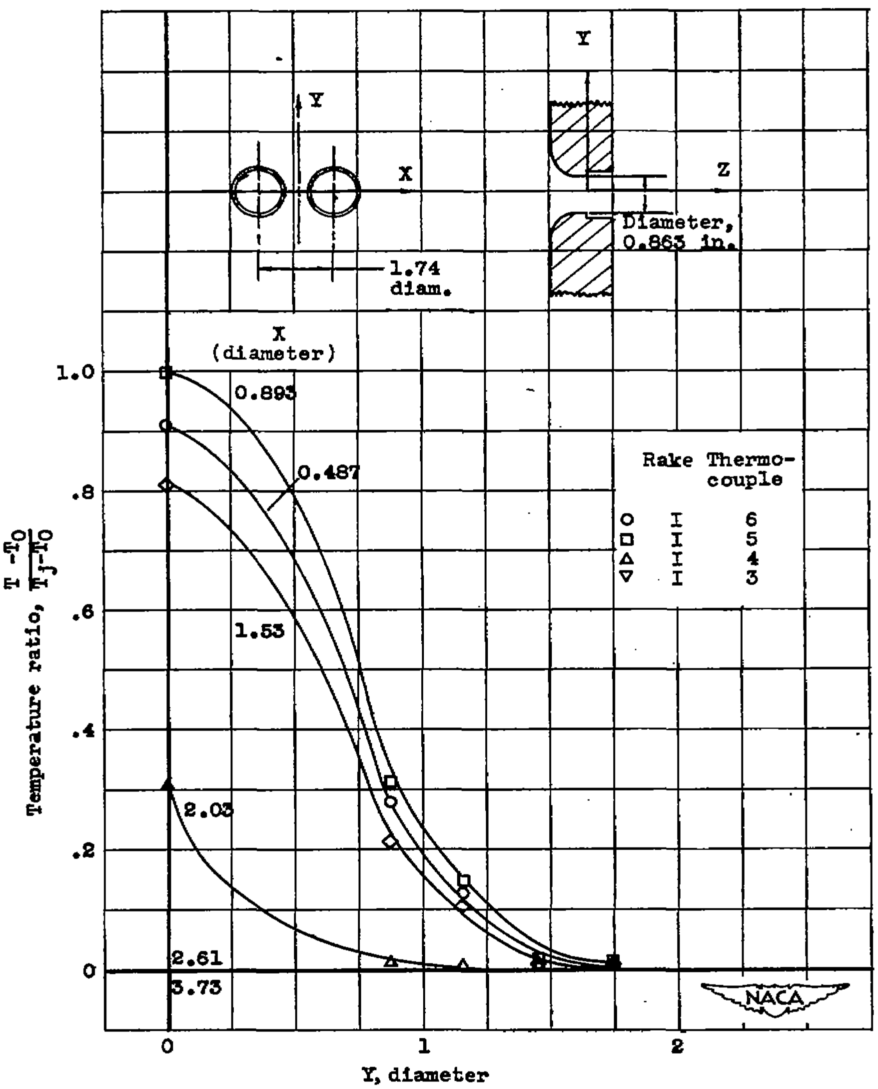
Figure 6. - Temperature-ratio contours in YZ plane (X=0) for jets from twin unshrouded nozzle.

1195



(a) X, 0; Z, 4.02 diameters.

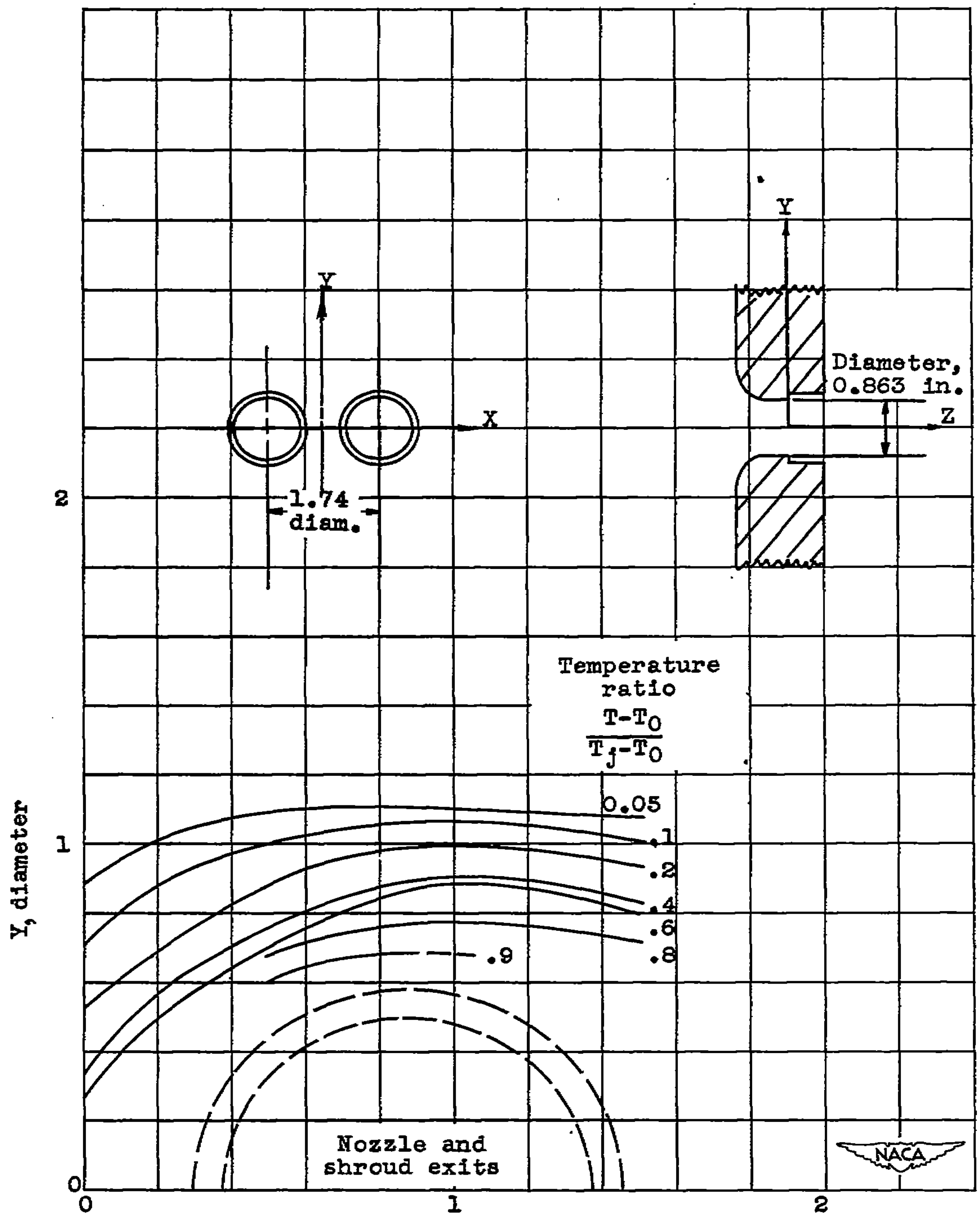
Figure 7. - Typical plot of data for twin shrouded nozzles.



(b) X, variable; Z, 4.02 diameters.

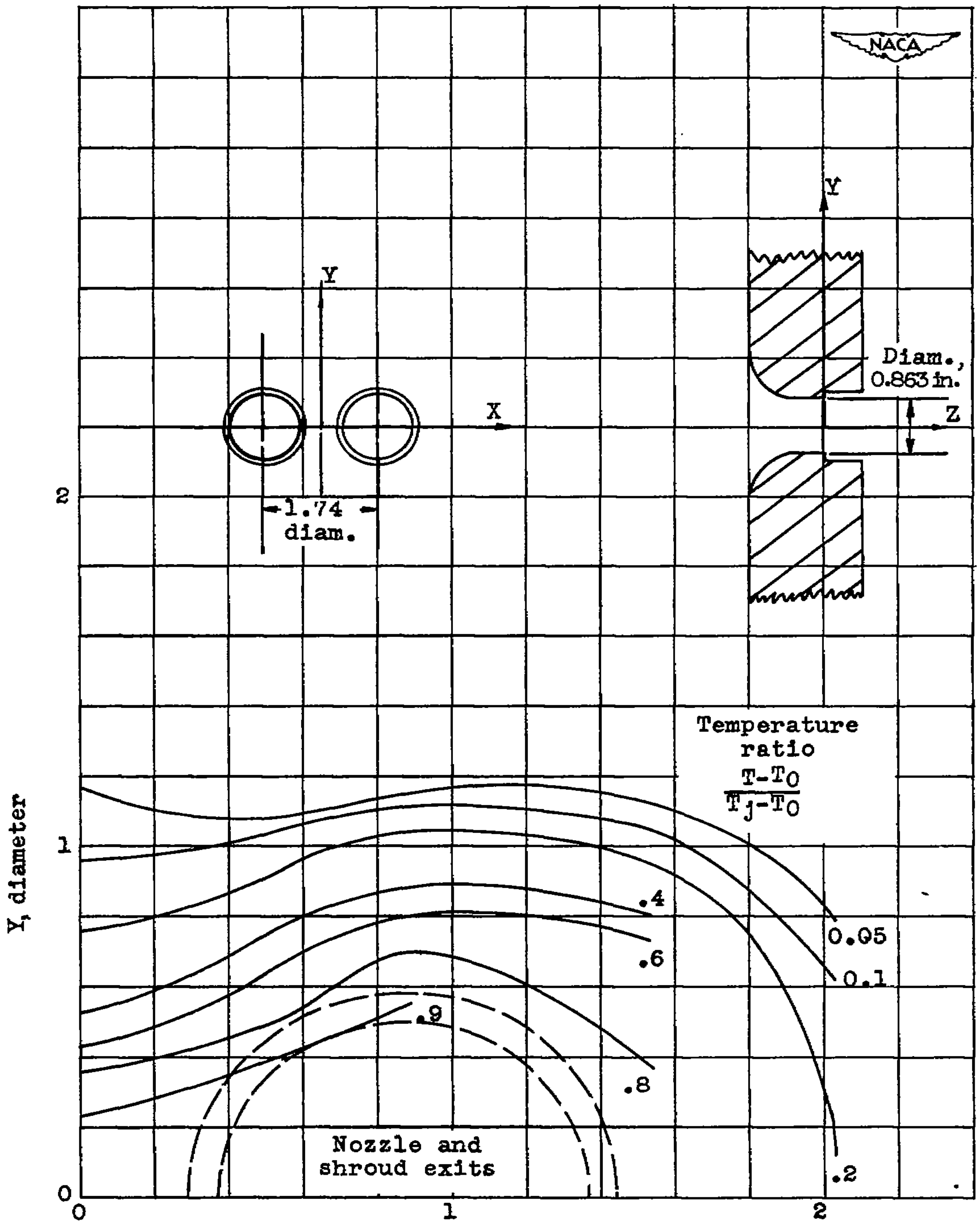
Figure 7. - Concluded. Typical plot of data for shrouded twin nozzles.

1195



(a) Z, 1.41 diameters.

Figure 8. - Temperature-ratio contours of one quadrant of wake from twin shrouded nozzles.



(b) Z, 2.28 diameters.

Figure 8. - Continued. Temperature-ratio contours of one quadrant of wake from shrouded nozzles.

1195

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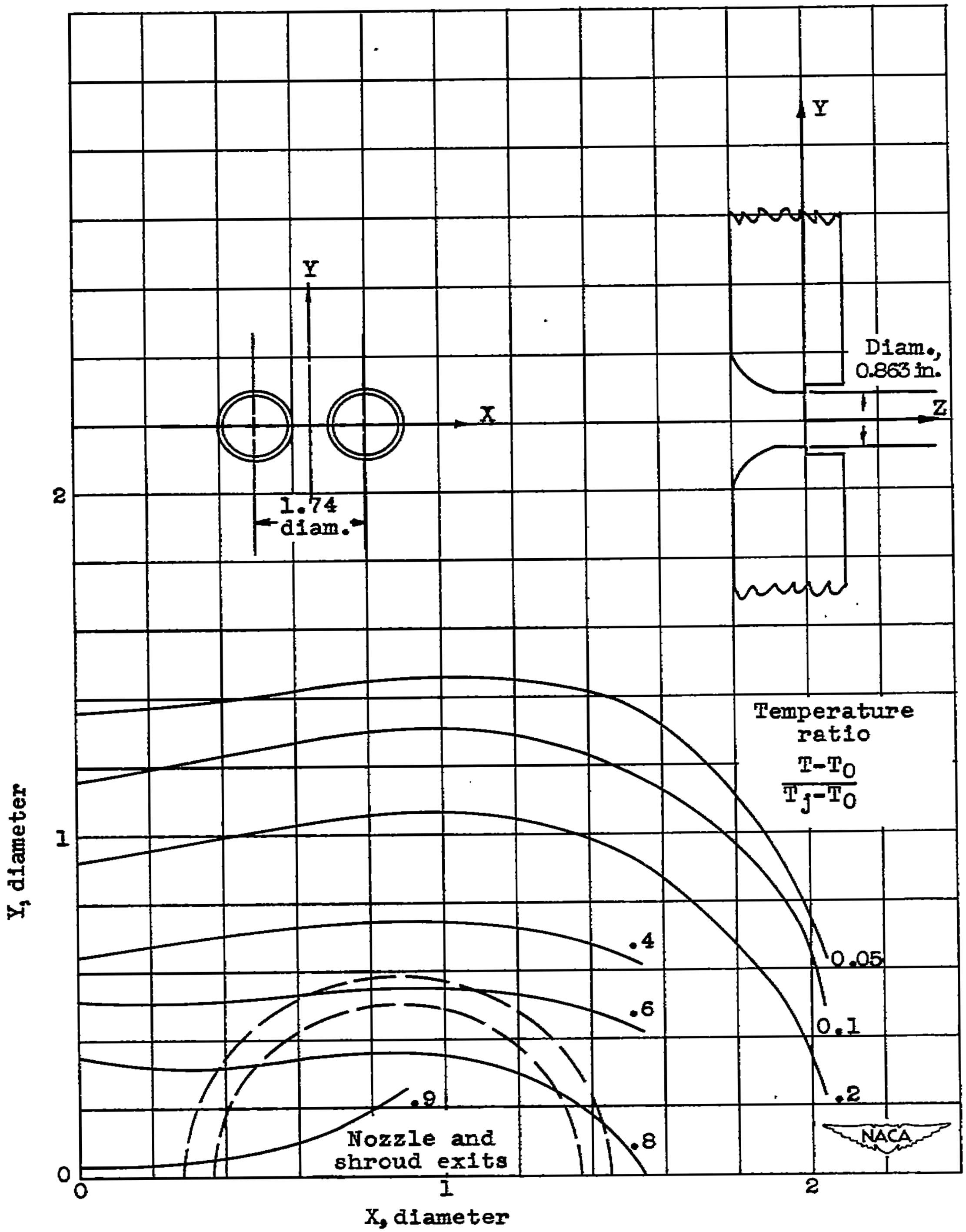

(c) Z, 4.02 diameters.

Figure 8. - Concluded. Temperature-ratio contours of one quadrant of wake from twin shrouded nozzles.

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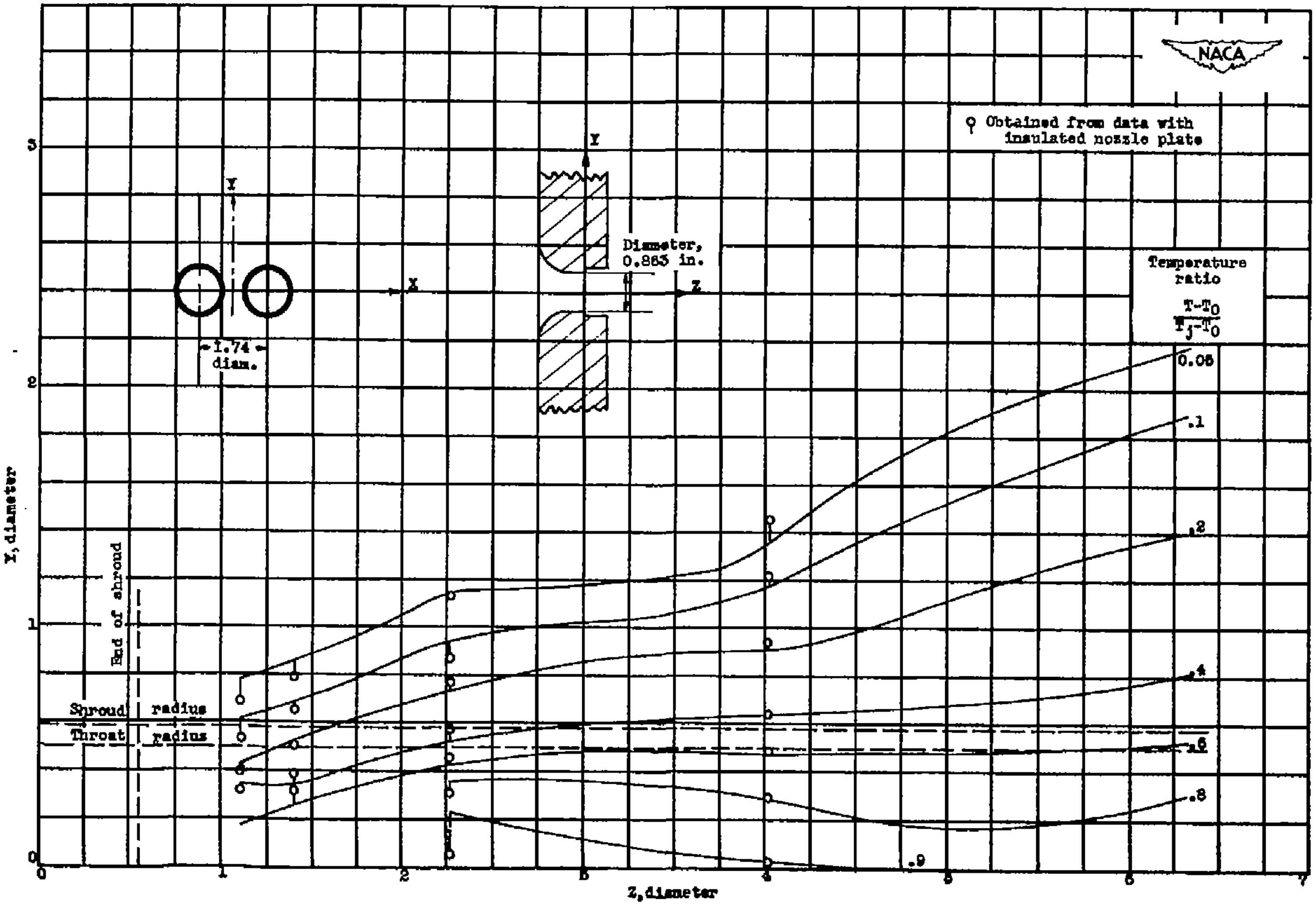

Figure 9. - Temperature-ratio contours in YZ plane (X=0) for jets from twin shrouded nozzles.

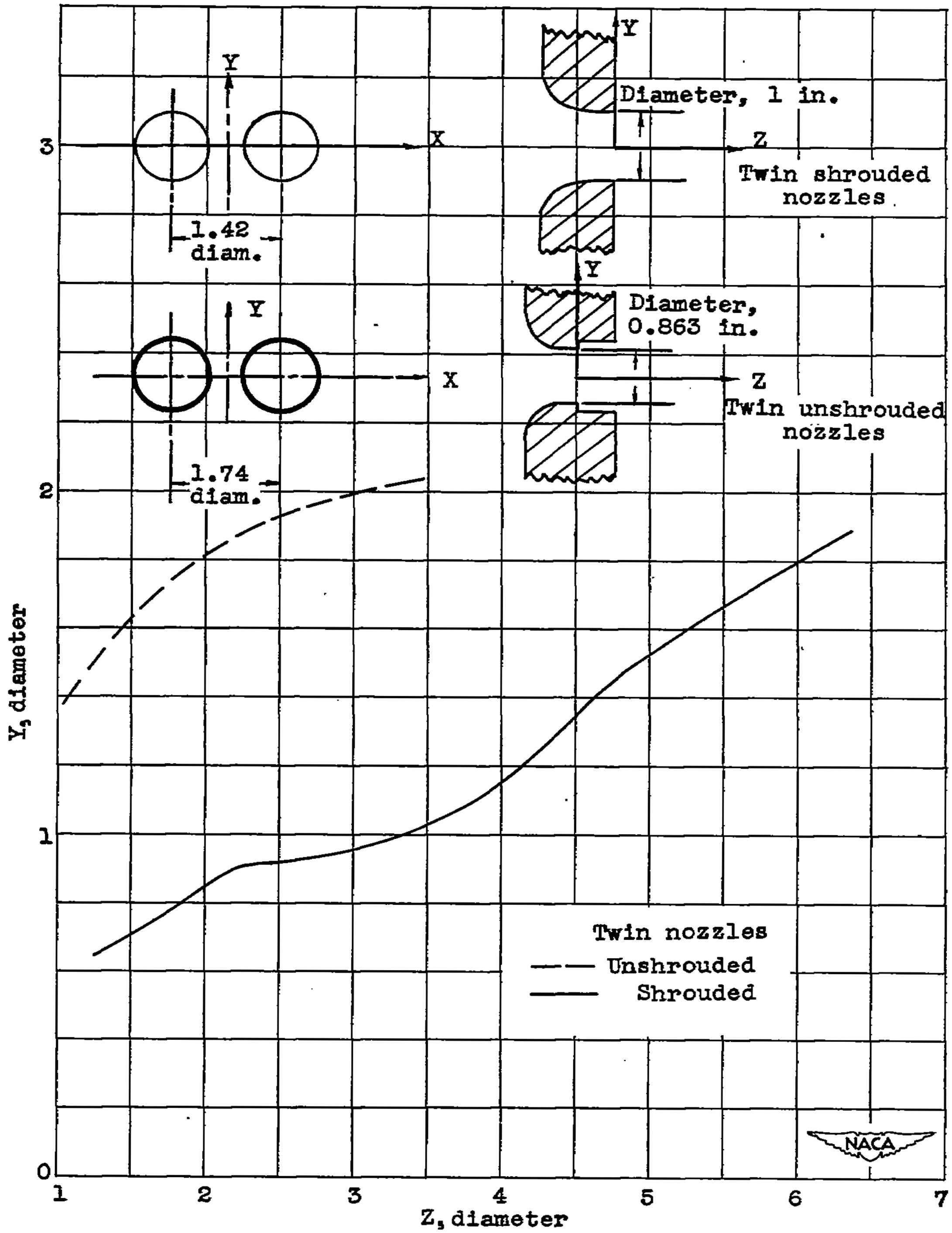

Figure 10. - Comparison of 0.1 temperature-ratio contours in YZ plane (X=0) for jets from twin unshrouded and twin shrouded nozzles.